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YOUNG KING MACKEREL, *SCOMBEROMORUS CAVALLA*, IN THE GULF OF MEXICO, A SUMMARY OF THE DISTRIBUTION AND OCCURRENCE OF LARVAE AND JUVENILES, AND SPAWNING DATES FOR MEXICAN JUVENILES

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ABSTRACT

To further our understanding of recruitment, spawning areas and times and stock structure we summarized all available published and unpublished information on early life stages of king mackerel. New data, 248 larvae and small juveniles (≤50 mm SL) from 676 neuston samples (1 × 2 m 0.947 mm and 0.760 mm mesh net) collected between 1983 and 1986 from west Florida (83°W long.) and the U.S. Mexican border (26°N lat.), are included. Previously unreported data (mostly large juveniles >50 mm SL) were collected during over 105,000 h of trawling between 1952 and 1985, and from an almadraba (pound net) and shrimp trawls in Mexico in 1985, 1986 and 1987. Sampling effort appropriate for collecting early life stages of king mackerel has been extensive (>7,200 collections), but heavily concentrated in U.S. waters during warm months (April to October). Larvae (≤10 mm SL) and small juveniles (11–50 mm SL) have been collected throughout the Gulf of Mexico (N = 1384), but mostly off Texas and between east Louisiana and northwest Florida. Most larger juveniles (>50 mm SL) have been collected off the Louisiana–Mississippi coast and southern Mexico. Seasonal occurrences of young stages clearly delineate the spawning season in U.S. waters as May to October, with a peak in September. Spawning dates backcalculated using daily ages determined from saggital otolith microstructure suggest that juveniles collected off Mexico were spawned January to September.

King mackerel, *Scomberomorus cavalla,* is a coastal pelagic scombrid that is widely distributed in the western Atlantic, occurring from Massachusetts to Rio de Janiero, Brazil and throughout the Gulf of Mexico and Caribbean Sea (Collette and Nauen, 1983). It is a valuable species, supporting diverse fisheries. In the southeastern United States and Mexico commercial catches were 2,542 metric tons (mt) (5.6 million lb) and 2,841 mt (6.3 million lb), respectively (U.S. Dept. Commer., 1985–1987; Fortune, 1987). U.S. recreational catches are estimated to be 2 to 10 times larger than commercial landings (Manooch, 1979; Deuel and Clark, 1968; Deuel, 1973; U.S. Dept. Commer., 1985–1987).

The purpose of this paper is to summarize the state of knowledge regarding distribution, occurrence, and seasonality of young king mackerel in the Gulf of Mexico. We have reviewed the fragmentary information in the literature, and combined it with our previously unpublished data. This information is relevant to understanding recruitment, spawning areas and times, as well as stock structure.

Materials and Methods

Because this analysis attempts to summarize all available information on the subject, we combined data from many sources. The references and life stages that were involved are given in Table 1. Data sources are also cited in figure legends as appropriate.

Previously unpublished data were collected on cruises of NMFS research vessels and various state research vessels participating in the Southeast Area Monitoring and Assessment Program (SEAMAP) (Richards et al., 1984; Kelley et al., 1985; see also Shaw and Drullinger, 1986). SEAMAP data were collected in 1982 and 1983 from samples obtained by single oblique bongo (0.333 mm mesh) and

Table 1. References from which king mackerel information was compiled

Reference	Stage
Bryan et al., 1982	Juvenile
Dwinell and Futch, 1973	Larval and small juvenile
Finucane et al., 1978	Larval and small juvenile
Hastings, 1972	Juvenile
Hoese, 1965	Larval, small and large juvenile
Houde et al., 1979	Larval
McEachran et al., 1980	Larval and small juvenile
Nakamura, 1976	Juvenile
Perret, 1971	Juvenile
Kelley et al., 1985	Larval
Lyczkowski-Shultz, 1978	Larval
Olvera Limas, MS	Larval
Richards et al., 1984	Larval
Roessler, 1967	Juvenile
Swingle, 1971	Juvenile
Williams and Gaines, 1974	Juvenile
Wollam, 1970	Larval

neuston (0.760 mm mesh) tows made at about 1.5 kn for 10 min. Samples were fixed in 10% seawater-formalin for 24 h then transferred to 95% ETOH. Additional details on standard SEAMAP protocol have been provided by Kelley et al. (1985).

We conducted neuston sampling on nine NMFS R/V CHAPMAN and R/V OREGON II cruises between 1983 and 1986 (Table 2). The 0.947 mm or 0.760 mm mesh 1 × 2 m neuston nets were towed at 1.8 $km \cdot h^{-1}$ for 10 min mostly at night. Samples were preserved in 10% formalin or 95% ETOH for 24 h, after which the original preservative was replaced with fresh ETOH.

Juveniles were collected by fish and shrimp trawls using various NMFS vessels from 1952 to 1985. Prior to 1974 different size trawls were used; therefore all effort was standardized to a 12 m (40 ft) headrope width net with 4.5 cm (1.75 in) stretch mesh cod end. Juveniles also were obtained from a Mexican almadraba (pound net) in Veracruz, Mexico in May 1985, and a shrimp trawl off Tampico, Mexico in July and September 1986 and October 1987 (fish obtained in Mexico were frozen or preserved in 95% ETOH in the field and returned to the Panama City Laboratory).

We used otolith microstructure to determine daily ages and estimate spawning dates of juveniles collected in Mexico. Sagittal otoliths were removed from each fish, cleaned and stored dry. Otoliths were prepared for examination by mounting, concave (lateral) surface up, on glass slides using thermoplastic cement. The ring microstructure was made visible by polishing each otolith by hand on 600 and 1,200 grit surfaces. The interpretation of otolith microstructure followed DeVries et al. (in press).

To make ring counts otolith mounts were immersed in oil to eliminate the visibility of polishing scratches, then viewed at 400 × on a compound microscope. Counts were made independently by three readers. We used the mean of the three ring counts as the count for each otolith. Spawning date of each fish was then estimated by subtracting its daily age from the date of capture.

We present larval and small juvenile areal and seasonal distribution results as both frequency of occurrence and catch-per-sample. Only crude standardization for effort to index abundance (catch-per-sample) was possible because units of effort were unequal (i.e., bongo, neuston, nekton, Tucker trawl and meter nets were all used with variable sampling times, and flow meters were not always used). We estimated catch-per-sample (I) according to the expressions $I = C/E_{adj.}$ and $E_{adj.} = Esd$. C was the total number of larvae and small juveniles collected by all gears in the U.S. Gulf of Mexico per 2°W long. interval (97°W–81°W) as reported in Dwinell and Futch (1973), McEachran et al. (1980), Houde et al. (1979), SEAMAP 1982 and 1983 (Richards et al., 1984; Kelley et al., 1985), Lyczkowski-Shultz (1987) and our new data. E is equivalent to the total number of samples collected in U.S. waters by all gears per 2°W long interval (97°W–81°W) or per month as reported in the above cited references. E was then adjusted downward according to the proportion of samples collected from April to October (s) and over waters ≤200 m deep (d) to yield adjusted effort ($E_{adj.}$), the effort appropriate to collect young king mackerel.

We did not develop an index of abundance for juvenile results, but present only frequency of occurrence because the data were sparse, and no effort data were available for fish collected in Mexico.

Across-shelf distributions of larvae and small juveniles were derived using data presented in Dwinell

Table 2. Samples and collections of previously unpublished king mackerel data included in this report

Vessel	Cruise No.	Area	Date	Samples (no.)	Sampling gear	No. fish
Oregon II	135	Northern and western Gulf of Mexico	5–9 June 1983	7	Neuston	—
Oregon II	145	Northern and western Gulf of Mexico	8–19 July 1984	23	Neuston	1
Oregon II	153	Northern and western Gulf of Mexico	10 June–18 July 1985	102	Neuston	49
Chapman	85-05(06)	Western Gulf of Mexico off Texas	30 July–8 Aug 1985	44	Neuston	—
Oregon II	159	Northern and western Gulf of Mexico	22 April–23 May 1986	145	Neuston/bongo	—
Chapman	86-03(12)	Northern Gulf of Mexico	6 May–18 May 1986	76	Neuston	—
Oregon II	160	Northern and western Gulf of Mexico	10 June–18 July 1986	42	Neuston	75
Oregon II	161	Mississippi River delta, eastern Gulf of Mexico and Atlantic coast	2 Sept–26 Sept 1986	126	Neuston	19
Chapman	86-05(14)	Mississippi River to Brownsville, Texas	2 Sept–26 Sept 1986	111	Neuston/bongo	104
				676		248

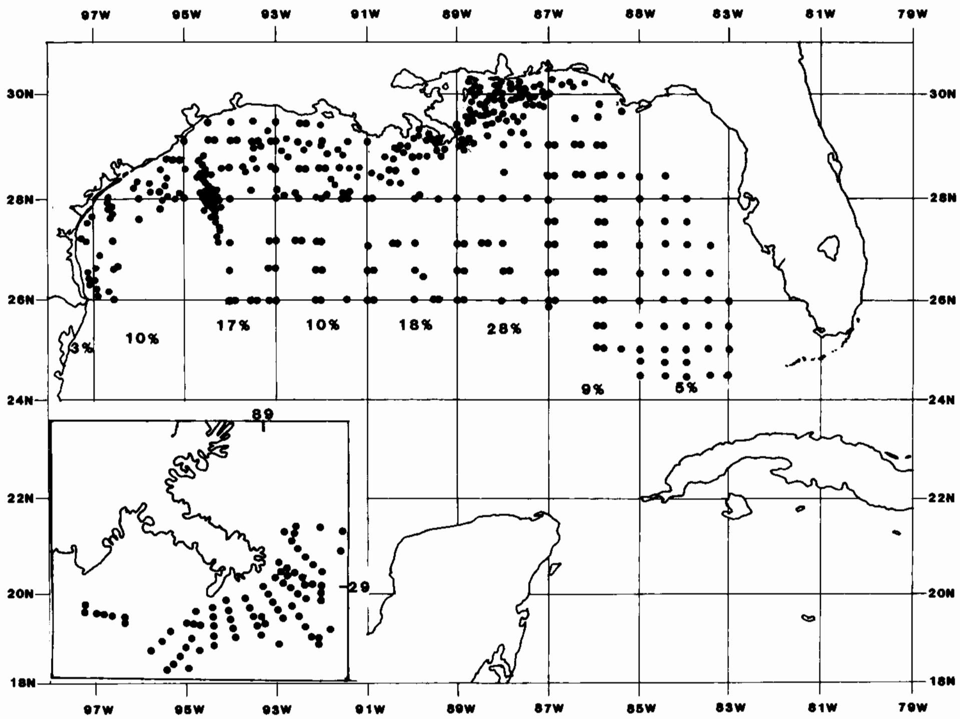

Figure 1. Geographic distribution of neuston and bongo sampling (N = 676) previously unreported in the literature. Percent of total samples collected is indicated for every 2°W longitude. Inset indicates sampling off the Mississippi River delta.

and Futch (1973), McEachran et al. (1980), SEAMAP 1982 and 1983 (Richards et al., 1984; Kelley et al., 1985) and our new data combined. Dwinell and Futch (1973) data are presented as frequency of occurrence by station depth that we determined by plotting stations on a nautical chart. We did not attempt to calculate an abundance index because effort data were not given for each station; however, sampling was approximately equal at each station. SEAMAP 1982 and 1983 (Richards et al., 1984; Kelley et al., 1985) and our data are also presented as frequency of occurrence, and not an abundance index, because of mixed and unequal units of effort (i.e., different sampling gears), and the number of SEAMAP samples at depth was not extractable from the reference material. However, because SEAMAP and our sampling was according to a systematic protocol, effort was approximately equal by depth across the continental shelf. We estimated means and error estimates of abundance by depth directly from McEachran et al. (1980).

Results and Discussion

Effort.—Sampling effort that was suitable to collect early life stages of king mackerel in the Gulf of Mexico has been considerable, widely distributed both temporally and spatially in U.S. waters, but temporally restricted off Mexico. We collected 676 neuston samples between west Florida (83°W long.) and the U.S. Mexican border (26°N lat.) (Table 2). However, about 60% of the sampling was concentrated between Alabama (87°W long.) and west Louisiana (93°W long.) (Fig. 1). All the sampling occurred on the continental shelf ($\leq$200 m depth) from April to September.

SEAMAP conducted extensive ichthyoplankton sampling throughout the Gulf of Mexico in 1982 and 1983 (Richards et al., 1984; Kelley et al., 1985). For the

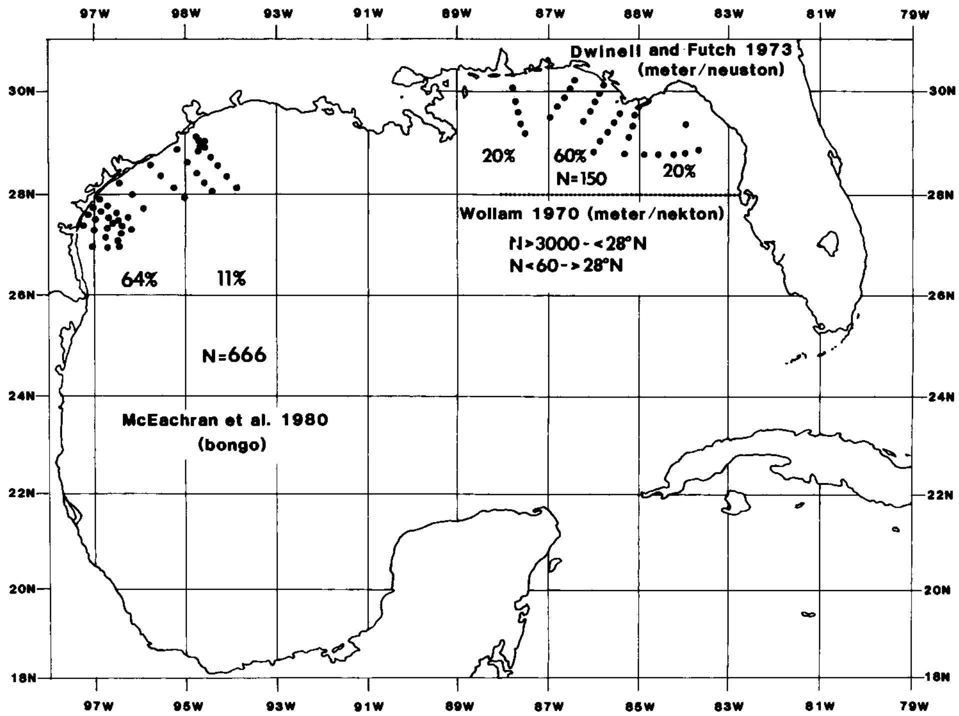

Figure 2. Geographic distribution of ichthyoplankton samples reported in McEachran et al. (1980), Dwinell and Futch (1973) and Wollam (1970); and percent of the total samples collected every 2° W longitude.

most part, stations were located 55.6 km (30 nm) apart on a systematic sampling grid. Samples (1,101 in 1982 and 1,029 in 1983) were collected from February through July and during October and November. The percentage of samples in U.S. waters collected on the continental shelf (≤200 m depth) was 49% in 1982 and 61% in 1983. In 1982 Mexican vessels participating in SEAMAP sampled extensively off the entire Mexican coast during May and June. In 1986, 76 bongo stations in Mexican waters off the Laguna Madre to Cabo Catoche were occupied in April and May; an additional 38 bongo stations were sampled during August from the Laguna Madre south to Rio Nauda and out to about 96°W lat. (Olvera Limas et al. MS).[1]

Other (past and recent) surveys have also contributed important sampling effort (Fig. 2). Wollam (1970) examined over 3,000 meter and nekton net samples from the southeastern Gulf of Mexico south of 28° lat., but only approximately 60 from north of that latitude. Dwinell and Futch (1973) collected 150 meter and neuston net samples on the continental shelf off northwest Florida and Alabama from June to October. McEachran et al. (1980) collected 666 bongo net samples on the continental shelf off Texas; 62% were taken from April to October and 38% from November to March. The west and northwest Florida shelf was sampled using bongo nets by Houde et al. (1979) (Fig. 3). Although most of Houde et al.'s (1979)

[1] Olvera Limas, R. M., J. A. Garcia-Borbon and J. L. Cerecedo G. Distribution y abundancia de larvas de la familia Scombridae en la zona economica exclusiva del Golfo de Mexico. Inst. Nat. Pesca, Dept. Plancton. 24 pp. Unpublished.

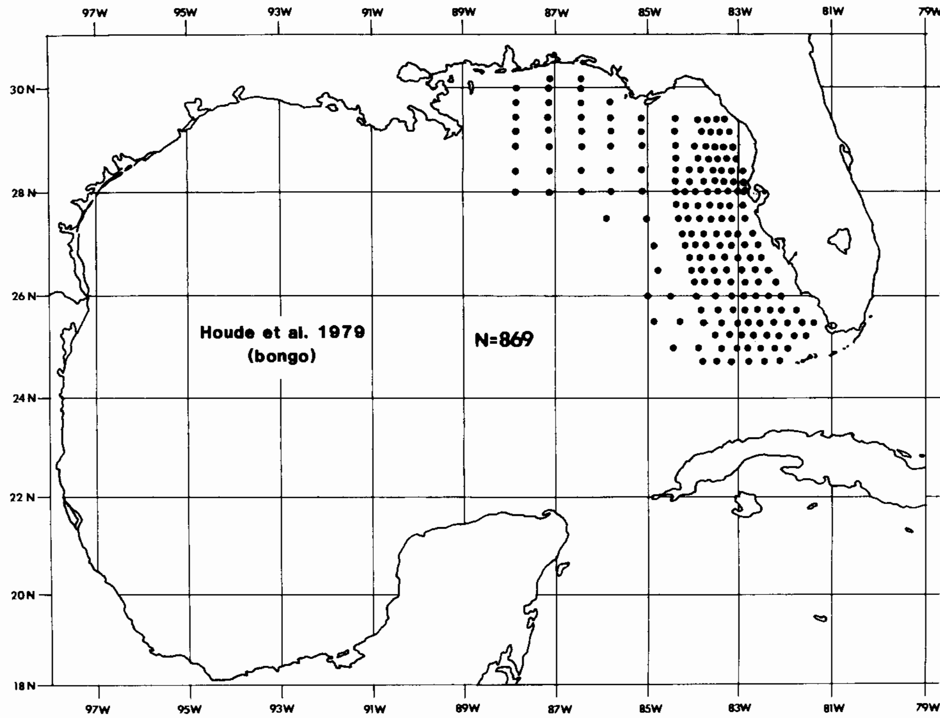

Figure 3. Geographic distribution of bongo samples reported in Houde et al. (1979).

sampling (65%) was during warm months when young king mackerel should have been available, northwest Florida was not sampled during warm months. From 1983–1986 Lyczkowski-Schultz (1987) made 307 ichthyoplankton collections (279 Tucker trawl and 28 bongo) on the east Louisiana-Mississippi-Alabama shelf. Sampling occurred from August through November; however, most was during September (52%) and October (39%).

Bottom trawling that has collected large juveniles has been extensive in the Gulf of Mexico since the 1950s. Between 1952 and 1985 NMFS conducted about 105,000 h of standardized trawling between Key West, Florida and Cabo Catoche, Mexico at the northeastern tip of the Yucatan Peninsula. However, trawling effort was heavily concentrated (80%) between Apalachicola, Florida and the Louisiana-Texas border (Table 3). Warm months (April–October) received 63% of the effort and cool months (November–March) 37%. In Mexico, large juveniles have been collected from an almadraba (in May) and trawls near Veracruz (in September and October), and off Tampico (in July).

Sampling effort, although extensive, may not be adequate to provide a comprehensive picture of the temporal and spatial distribution of early life stages. Mexico has not been sampled for larvae and small juveniles except during April, May, June, and August, and trawling by research vessels along the Mexican coast that might have collected large juveniles has been very limited, particularly from November to March (Table 3).

Size.—Sizes of young king mackerel vulnerable to the different sampling gears varied. Bongo and meter nets collected larval king mackerel mostly <10 mm SL, and modal length about 3 mm SL (Fig. 4). Neuston nets collected larvae and small

Table 3. Temporal and spatial distribution of NMFS trawling effort (×10) in hours (and percent) in the Gulf of Mexico from 1952–1985

Geographic area	Apr–Oct	Nov–Mar	Total
Key West, FL to Apalachicola, FL	346	95	441 (4.2)
Apalachicola, FL to Mississippi Delta	3,253	1,860	5,113 (48.4)
Louisiana	1,896	1,415	3,311 (31.3)
Texas	483	215	698 (6.6)
U.S.-Mexican border to Rio Gonzalez, Mex.	271		271 (2.6)
Rio Gonzalez, Mex. to Cabo Catoche, Mex.	449	288	737 (6.9)
	6,698 (63.4)	3,873 (36.6)	10,571

juveniles ranging from 6 to 33 mm SL and 10 mm modal SL (Fig. 4). NMFS and Mexican shrimp trawls collected large juveniles ranging from about 100 to 600 mm FL (Fig. 5). Juveniles obtained from Mexican trap nets were smaller than those collected in trawls (40 to 110 mm FL) (Fig. 5).

Spatial Distribution and Abundance.—Frequency of occurrence and/or catch-per-sample of all early life stages of king mackerel provide an incomplete picture of spatial distribution. Larvae (≤10 mm SL) and small juveniles (11 to 50 mm SL) have been collected widely throughout the Gulf of Mexico, but were most abundant off Texas, and east Louisiana to northwest Florida. Less than 10 larvae and small juveniles have been collected off Mexico, and they were nearly as rare off peninsular west Florida (Fig. 6). The more sizable catches off Texas, northwest Florida and east Louisiana to Alabama occurred in late August and early September 1976 and 1977 (McEachran et al., 1980), late June and early September 1969 (Dwinell and Futch, 1973), late August and early September 1982–1986 and mid-September 1983–1986 (Lyczkowski-Shultz, 1987), respectively.

These results may suggest that spawning off Texas is reduced from its mid-1970s level; reduced spawning could be a consequence of fishing. Larvae and small juveniles were abundant off Texas in the mid-1970s, but in recent sampling (i.e., SEAMAP) these early life stages have occurred infrequently. Fishing may be the reason because it has (1) truncated the size structure of the fisheries (Trent et al., 1983; Manooch et al., 1987) and (2) reduced spawning biomass (NMFS 1987), since the mid-1970s. Smaller fish that comprise the present spawning stock may not migrate as far west in the Gulf of Mexico (i.e., to Texas) as spawners did in the mid to late 1970s. Mark-recapture data on king mackerel show that total migration distance from the south Florida wintering grounds is positively correlated with length of fish (Williams and Godcharles, 1984).[2] Migratory fish commonly stratify by size/age along their migratory route, with largest individuals traveling the greatest distance from the wintering grounds, e.g., American shad,

[2] Williams, R. O. and M. F. Godcharles. 1984. King mackerel tagging and stock assessment. Completion Report, Florida Dept. Nat. Resort., Project 2-341-R. Unpublished report, 45 pp. plus figures and tables.

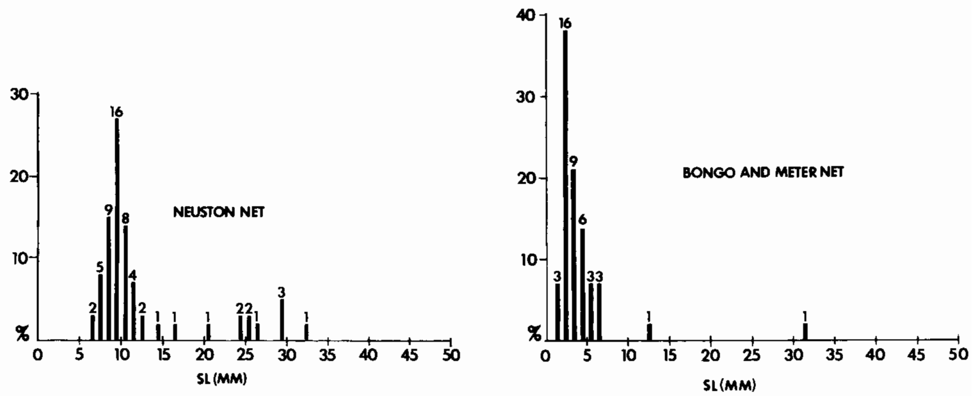

Figure 4. Size-frequency distribution of young king mackerel collected in neuston, bongo and meter nets. Sample size is given over each bar.

Alosa sapidissima, (Leggett and Carscadden, 1978), weakfish, *Cynoscion regalis,* (Shepherd and Grimes, 1984), and menhaden, *Brevoortia tyrannus,* (Nicholson, 1978).

Large juveniles (>50 mm SL) occurred most frequently off the Louisiana-Mississippi coast and off southern Mexico (Fig. 7). However, the vast majority of effort has also been expended there, i.e., 80% of NMFS trawling between 1952 and 1985 was between Apalachicola, Florida and the Texas-Louisiana border.

Across-Shelf Distribution.—The distribution of early life stages of king mackerel across the continental shelf appears to vary by life stage and location. Off northwest Florida and Alabama, Dwinell and Futch (1973) collected larvae and small juveniles across the shelf where station depths ranged from 15 to 915 m; modal occurrence was at 35 m (Fig. 8). Data for Louisiana and Mississippi show a similar distribution across the shelf (15 to 185 m), with most occurring from 25 to 35 m (Fig. 9B). Off the east Louisiana–Mississippi–Alabama shelf larvae occurred most commonly over 11 to 18 m depths, but most sampling was over depths <20 m (Lyczkowski-Shultz, 1987). Off Texas, McEachran et al. (1980) also found larvae

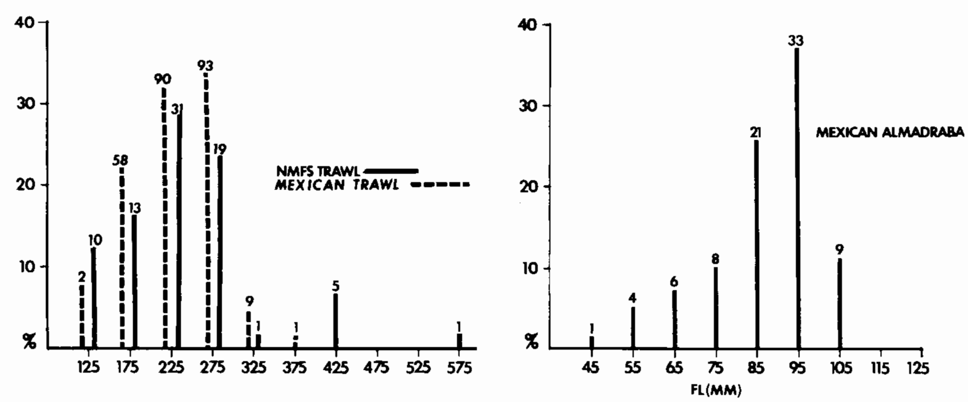

Figure 5. Size-frequency distribution of juvenile king mackerel collected by NMFS research trawls, Mexican shrimp trawls and a Mexican almadraba. Sample size is given over each bar.

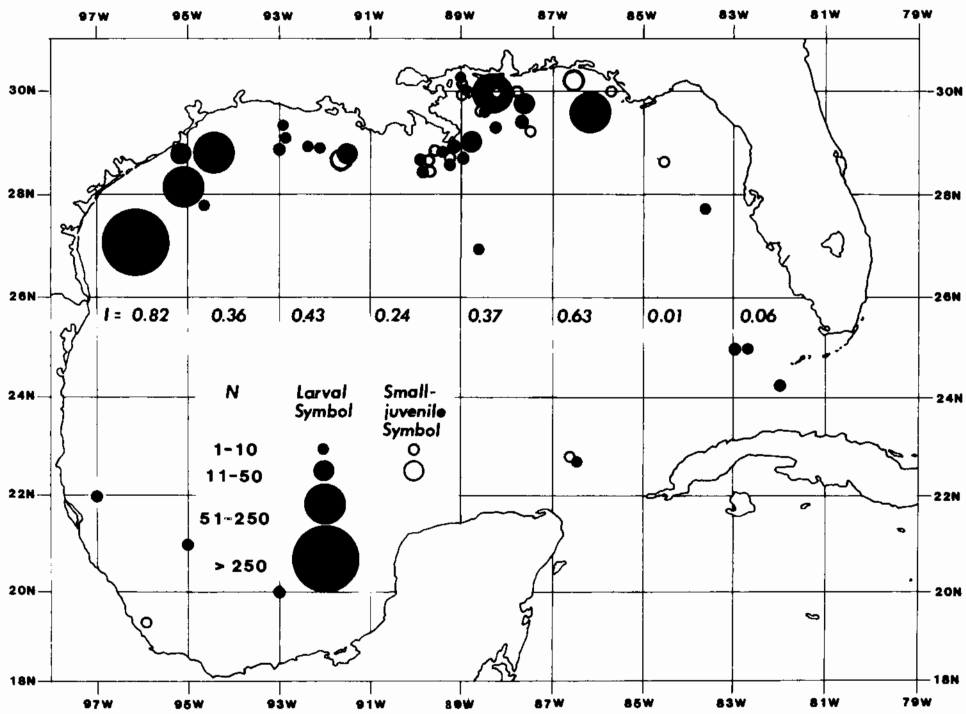

Figure 6. Distribution and occurrence of larval (≤10 mm SL) and small juvenile (11 to 50 mm SL) king mackerel in the Gulf of Mexico through 1986. Larvae are represented by closed circles and postlarvae by open circles. I = approximate catch-per-sample of larvae and small juveniles (N = 1,384).

and small juveniles across the entire continental shelf, but highest abundances were over the middle shelf (65 to 135 m), deeper than off northwest Florida, Alabama, Louisiana and Mississippi (Fig. 10).

In contrast, larger juveniles appear to be most common over the inner shelf in shallower depths. Modal frequency of occurrence of fish collected by NMFS research trawls from 1958–1985 was 15 m depth (Fig. 9A).

Seasonality.—Seasonal distribution of all early life stages indicates the spawning season of king mackerel in the U.S. Gulf of Mexico, but the pattern is unclear for the extreme southwestern Gulf of Mexico. The seasonal frequency of occurrence and crude catch-per-sample of larvae and small juveniles as determined from all sources clearly defines the spawning season from Texas to northwest Florida as May to October, and indicates that most spawning occurs June through September, with a clear peak in September (Fig. 11A). The same spawning seasonality is reported for the Gulf of Mexico by Finucane et al. (1986) using gonadosomatic indices, gonad staging and egg diameter data. The frequency of occurrence of juveniles shows seasonal peaks in July and October; presumably the October peak represents the September mode of larvae and small juveniles at a slightly older age. The third seasonal peak of juveniles in May consists almost entirely of juveniles collected in the almadraba in Veracruz, Mexico (Fig. 11B).

Frequency of occurrence of larvae and small juveniles supports the conclusion that spawning in the Gulf of Mexico occurs from May through September over the continental shelf from Cape San Blas, Florida to Texas. Larval and small

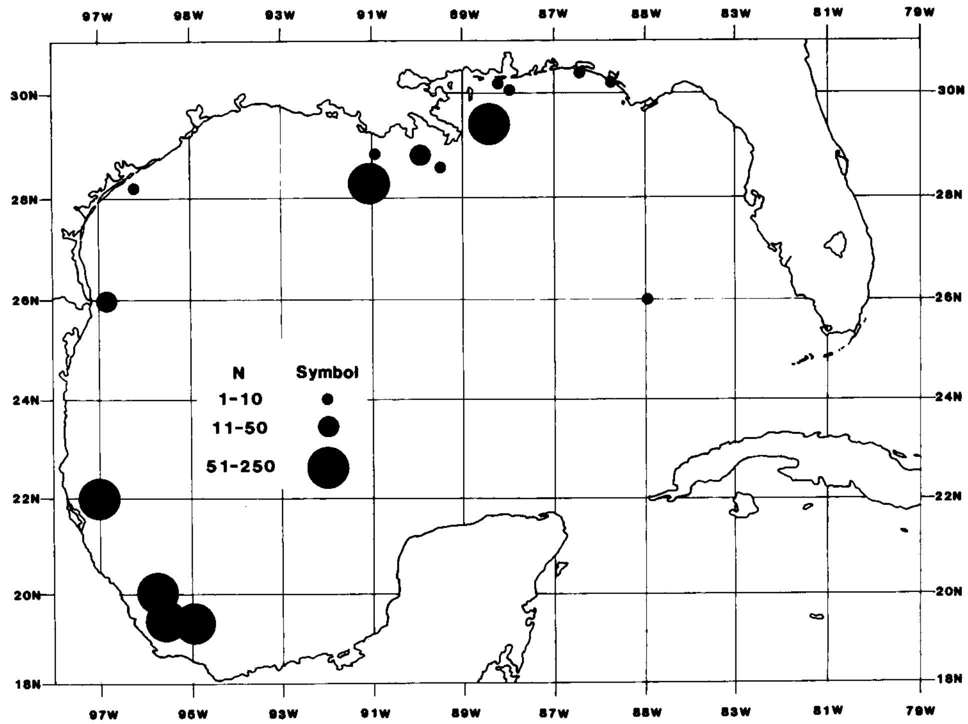

Figure 7. Distribution and occurrence of large juvenile (>50 mm SL) king mackerel collected in the Gulf of Mexico by NMFS trawls, Mexican shrimp trawls and a trap net (N = 658).

juvenile collections since 1982 have produced more of these early life stages off Louisiana, Mississippi, and Alabama than off Texas. Also, the across-shelf distribution of catches indicates that these early life stages are most abundant in middle-shelf waters off Texas (65–135 m), but are most common at shallower depths (20–40 m) over the northwest Florida-Alabama-Mississippi-Louisiana shelf. If spawning is associated with oceanographic features (e.g., the Mississippi River discharge plume) that create a microhabitat offering abundant food (Finucane et al., in press; Grimes et al., unpubl. data) and thus superior growth (DeVries et al., in press), then the across-shelf distribution differences for young king mackerel off Texas may indicate that spawning off Texas is associated with different oceanographic features (e.g., thermal fronts).

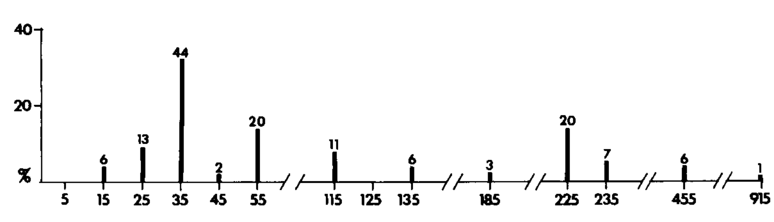

Figure 8. Across-shelf distribution of larval and small juvenile king mackerel collected off Alabama and northwest Florida by Dwinell and Futch (1973). Sample size is given over each bar.

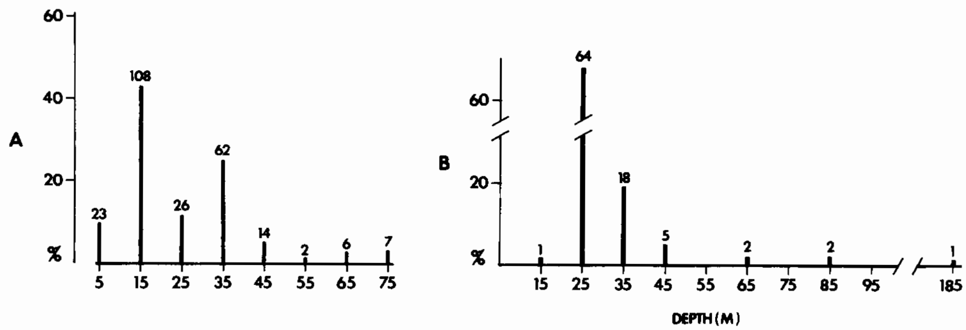

Figure 9. Across-shelf distribution of large juveniles (>50 mm SL) collected by NMFS research trawls (A) and larvae and small juveniles (≤50 mm SL) collected off Louisiana and Mississippi by SEAMAP and us (B).

Backcalculated Spawning Dates.—We extracted and mounted the sagittal otoliths of 264 juvenile king mackerel collected in Mexico, and were able to estimate ages for 240. Unsuccessful aging of otoliths resulted from mistakes in preparation (e.g., over polishing). The fish ranged in size from about 45–300 mm FL (Fig. 5). Each otolith growth increment consisted of one optically transparent layer and one less transparent layer. The first 9 or 10 increments were closely spaced and distinct; the remaining increments were less distinct, particularly along the otolith margin. Evidence for daily deposition of growth increments in larval and small juvenile king mackerel otoliths is presented in DeVries et al. (in press). The growth increments we observed were identical to those described by DeVries et al. (in press), thus we assume the growth increments we observed were also deposited daily. There was considerable variation in length at daily age (mean of three independent readings), and as expected, the variation increased with age (Fig. 12). This variation was due to (1) actual variation in growth of individual fish, and

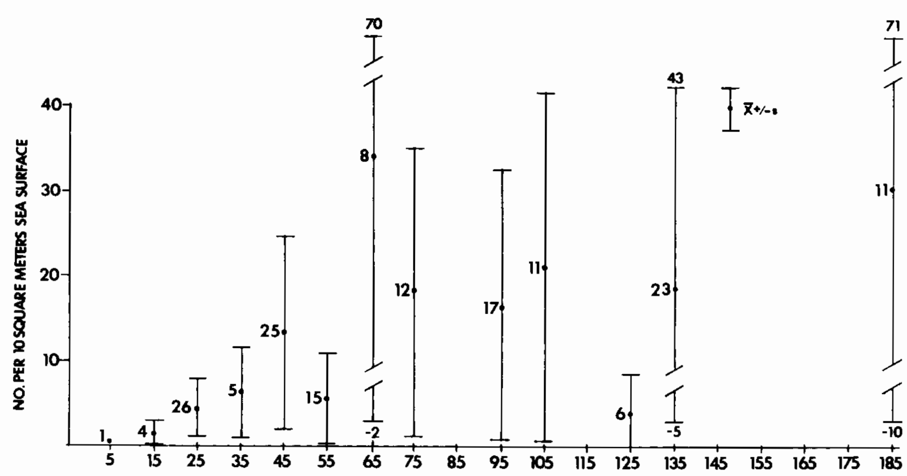

Figure 10. Across-shelf distribution of larval and small juvenile (≤50 mm SL) king mackerel off Texas (McEachran et al., 1980). Sample size is indicated beside the mean for each depth interval.

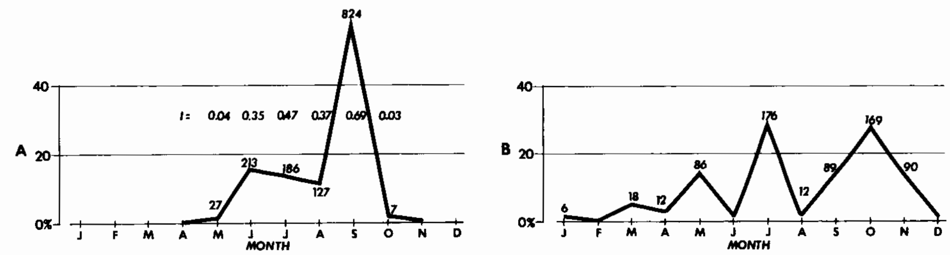

Figure 11. Monthly frequency of occurrence of larval and small juvenile (≤50 mm SL) (A) and large juvenile king mackerel (>50 mm SL) (B) in the Gulf of Mexico (compiled from McEachran et al., 1980; Dwinell and Futch, 1973; Wollam, 1970; SEAMAP 1982 and 1983 collections; Lyczkowski-Shultz, 1987; our data and NMFS shrimp trawls, 1952–1985). Sample sizes are indicated for each month. I = approximate catch-per-sample for larvae and small juveniles.

(2) imprecision in aging (i.e., disagreement among readers). Using a sub-sample of 191 otoliths we evaluated aging precision by three independent readers. In 35% (67) no single reading was >10% different from the mean of the three readings, 61% (117) agreed within 15% different and 80% (154) agreed to within 20% different. Because we intended to use age data to determine if backcalculated spawning dates for Mexican fish were different from the temporally restricted (summer) spawning of king mackerel along the U.S. Gulf of Mexico coast, we deemed this precision acceptable.

By subtracting daily ages from capture dates we produced spawning dates ranging from January to September for juvenile king mackerel collected in Mexican waters (Fig. 13). Because these juveniles were not collected according to a regular

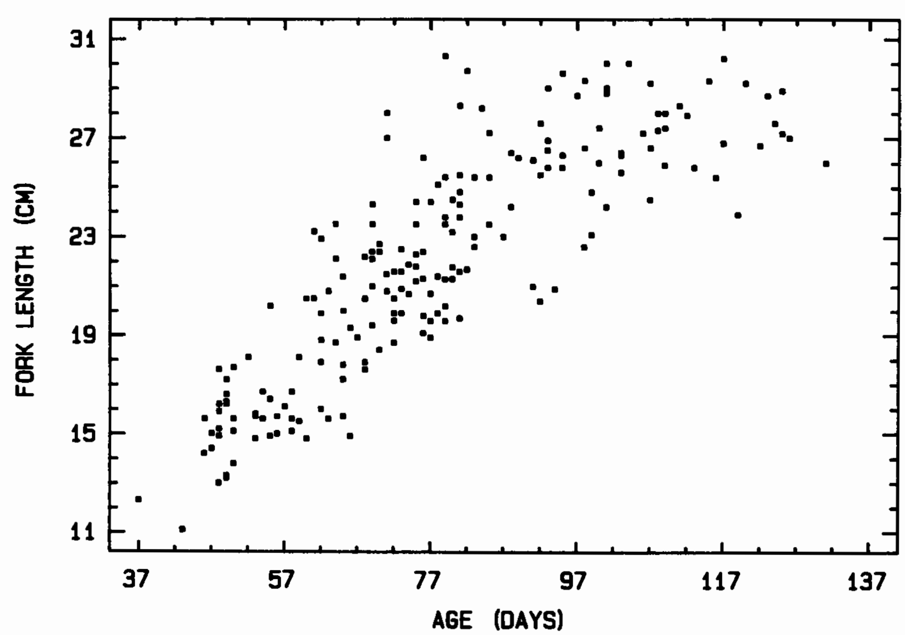

Figure 12. Scatterplot of length at mean age of 191 juvenile king mackerel collected in Mexican waters.

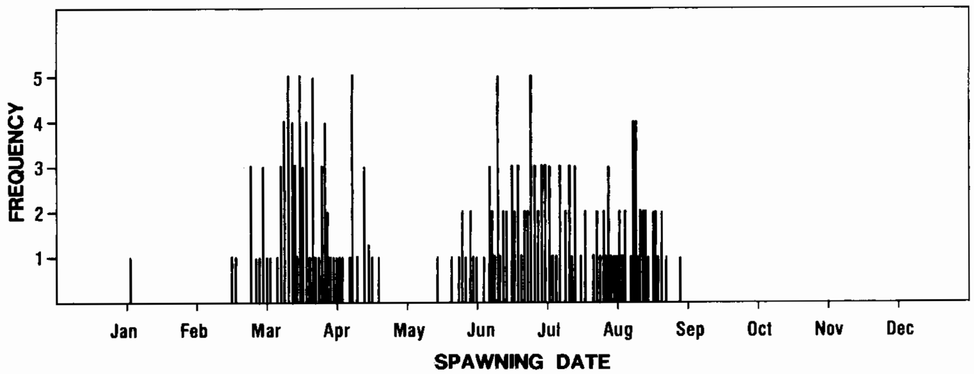

Figure 13. Frequency distribution of back-calculated spawning dates of juvenile king mackerel collected in Mexican waters.

sampling design, the data do not indicate spawning frequency, only that it occurred. Although our data do not demonstrate year-round spawning in Mexican waters, that may be the case. Year-round reproduction, with peak spawning from October to June, has generally been reported for king mackerel in more tropical locations (e.g., Menezes (1969), Ivo (1972) and Gesteira and Mesquita (1976) for Ceara in northeastern Brazil and Sturm and Salter (in press) for Trinidad).

The extended spawning period (January to September) for king mackerel from the extreme southwestern Gulf of Mexico is clearly different from the May to October period in U.S. Gulf of Mexico waters, and probably indicates that a separate spawning group of king mackerel exists in Mexican waters.

Acknowledgments

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